

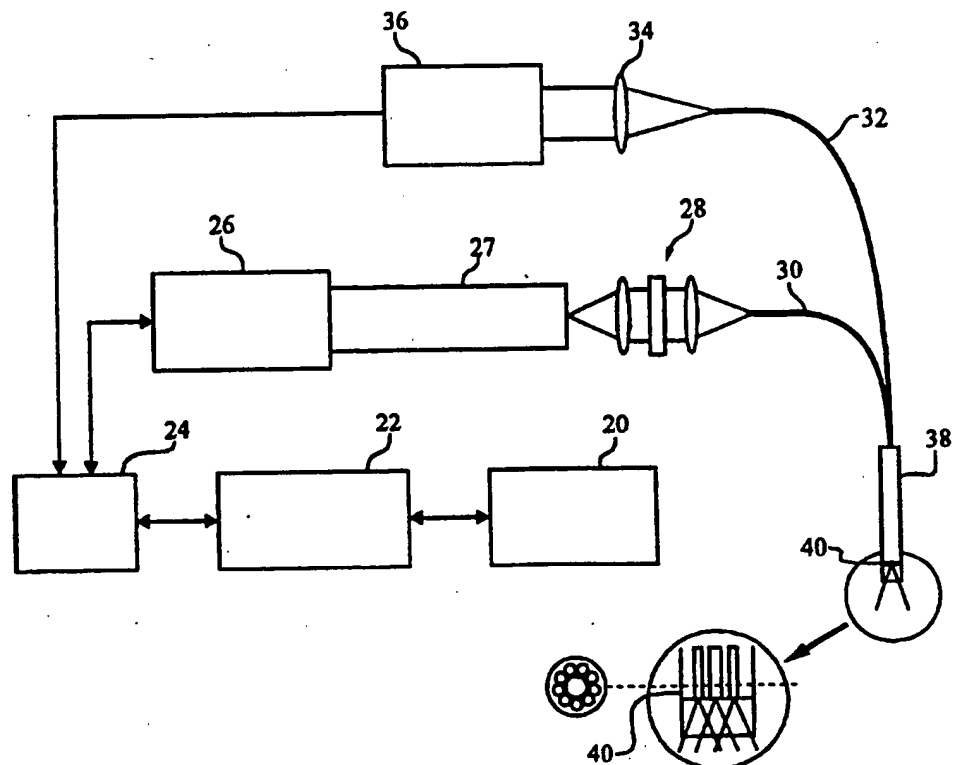
INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

| | | | |
|--|--|---|--|
| (51) International Patent Classification ⁵ : A61B 6/00 | | A1 | (11) International Publication Number: WO 94/26168 |
| | | | (43) International Publication Date: 24 November 1994 (24.11.94) |
| (21) International Application Number: PCT/US94/05230 | | (81) Designated States: AT, AU, BB, BG, BR, BY, CA, CH, CN, CZ, DE, DK, ES, FI, GB, GE, HU, JP, KG, KP, KR, KZ, LK, LU, LV, MD, MG, MN, MW, NL, NO, NZ, PL, PT, RO, RU, SD, SE, SI, SK, TJ, TT, UA, UZ, VN, European patent (AT, BE, CH, DE, DK, ES, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, ML, MR, NE, SN, TD, TG). | |
| (22) International Filing Date: 11 May 1994 (11.05.94) | | | |
| (30) Priority Data: 08/060,432 12 May 1993 (12.05.93) US | | | |
| (71) Applicant: BOARD OF REGENTS, THE UNIVERSITY OF TEXAS SYSTEM [US/US]; 201 West 7th Street, Austin, TX 78701 (US). | | Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i> | |
| (72) Inventors: RAMANUJAM, Nirmala; P.O. Box 4853, Austin, TX 78765 (US). MAHADEVAN, Anita; P.O. Box 8285, Austin, TX 78713 (US). RICHARDS-KORTUM, Rebecca; 715 Shade Tree Drive, Austin, TX 78748 (US). MITCHELL, Michele, Follen; 3460 Inwood Drive, Houston, TX 77019 (US). THOMSEN, Sharon; 3024 Pittsburg, Houston, TX 77005 (US). | | | |
| (74) Agent: BAHLER, David, D.; Arnold, White & Durkee, P.O. Box 4433, Houston, TX 77210 (US). | | | |

(54) Title: **DIAGNOSIS OF DYSPLASIA USING LASER INDUCED FLUORESCENCE**

(57) Abstract

Apparatus and in vivo methods for distinguishing normal and abnormal cervical tissue and detecting cervical intraepithelial neoplasia (CIN) in a diagnostic tissue sample. A source of electromagnetic radiation (36) is applied to the diagnostic cervical tissue sample and the presumptively known normal cervical tissue. Fluorescence intensity spectra induced in the diagnostic tissue sample and the presumptively known tissue by the radiation source is detected by at least one radiation detector (26). A computer (20) is programmed to measure a peak normal fluorescence intensity value in each of the normal fluorescence intensity spectra, to calculate an average peak normal fluorescence intensity from the peak normal fluorescence intensity values, to measure a peak fluorescence intensity value from the fluorescence intensity spectrum induced in the diagnostic tissue sample, to calculate a slope parameter which is indicative of tissue abnormality, to calculate relative peak fluorescence intensity as a function of the peak intensity value, the average peak normal intensity, and to detect tissue abnormality as a function of the slope parameter and the relative peak fluorescence intensity.



FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

| | | | | | |
|----|--------------------------|----|---------------------------------------|----|--------------------------|
| AT | Austria | GB | United Kingdom | MR | Mauritania |
| AU | Australia | GE | Georgia | MW | Malawi |
| BB | Barbados | GN | Guinea | NE | Niger |
| BE | Belgium | GR | Greece | NL | Netherlands |
| BF | Burkina Faso | HU | Hungary | NO | Norway |
| BG | Bulgaria | IE | Ireland | NZ | New Zealand |
| BJ | Benin | IT | Italy | PL | Poland |
| BR | Brazil | JP | Japan | PT | Portugal |
| BY | Belarus | KE | Kenya | RO | Romania |
| CA | Canada | KG | Kyrgyzstan | RU | Russian Federation |
| CF | Central African Republic | KP | Democratic People's Republic of Korea | SD | Sudan |
| CG | Congo | KR | Republic of Korea | SE | Sweden |
| CH | Switzerland | KZ | Kazakhstan | SI | Slovenia |
| CI | Côte d'Ivoire | LI | Liechtenstein | SK | Slovakia |
| CM | Cameroon | LK | Sri Lanka | SN | Senegal |
| CN | China | LU | Luxembourg | TD | Chad |
| CS | Czechoslovakia | LV | Latvia | TG | Togo |
| CZ | Czech Republic | MC | Monaco | TJ | Tajikistan |
| DE | Germany | MD | Republic of Moldova | TT | Trinidad and Tobago |
| DK | Denmark | MG | Madagascar | UA | Ukraine |
| ES | Spain | ML | Mali | US | United States of America |
| FI | Finland | MN | Mongolia | UZ | Uzbekistan |
| FR | France | | | VN | Viet Nam |
| GA | Gabon | | | | |

-1-

DESCRIPTIONDIAGNOSIS OF DYSPLASIA USING
LASER INDUCED FLUORESCENCE

5

BACKGROUND OF THE INVENTIONField of the Invention

10

The invention relates to methods and apparatus to differentiate between histologically normal and histologically abnormal tissues, and to differentiate neoplastic tissue from histologically abnormal non-neoplastic tissue.

15

Screening for Cervical Intraepithelial Neoplasia (CIN)

Although there has been a significant decline in the incidence and mortality of invasive cervical carcinoma over the last 50 years, there has been an increase in both the reported and actual incidence of CIN. As a result, it has been estimated that the mortality of cervical carcinoma may rise by 20% in the years 2000-2004 unless screening techniques for CIN are improved.

20

25

Present screening for CIN and cervical cancer is relatively inexpensive but labor intensive because it initially relies on the results of a Pap smear; a false negative error rate of 20-30% is associated with insufficient cell sampling and/or inexpert reading of Pap smears. Given an abnormal Pap smear, colposcopic examination of the cervix (with a magnifying lens) followed by colposcopically directed biopsy and histologic examination of the tissue sample can provide a diagnosis of CIN. Histologic confirmation of the diagnosis, while relatively time-consuming and expensive,

30

35

-2-

is necessary because the accuracy of classification among abnormal tissues by colposcopy alone is limited, even in experienced hands.

5 Improving the predictive value of colposcopy in distinguishing CIN from other abnormal tissues (e.g., tissue infected with human papilloma virus (HPV) or inflammatory tissue) could reduce the number of required number of biopsies and thereby increase the speed and
10 efficiency of the screening process. Diagnosis and treatment might be combined in a single office visit, with colposcopically directed treatments including loop electrosurgical procedures (LEEP), cryo and laser therapies, and chemopreventive agents. Further,
15 explication of improved methods to classify tissue as normal or abnormal, while not leading directly to a diagnosis of CIN, would reduce costs by allowing performance of colposcopy by medical technicians less skilled than trained colposcopists (usually physicians).

20

Spectroscopic Methods in Colposcopy

 Spectroscopic methods for differentiating cervical neoplasia from normal cervical tissue *in vivo* have been
25 described. The methods rely generally on observations that the fluorescence of abnormal tissue is significantly weaker than that of normal tissue at several excitation wavelengths, e.g., 330, 350 and 450 nm. This property has been used for spectroscopic identification of
30 histologically abnormal tissue. For example, *in vitro* fluorescence intensity comparisons at an excitation wavelength of 330 nm yielded positive predictive value, sensitivity and specificity of 86%, 88% and 75% respectively on colposcopically normal and abnormal
35 biopsies from the same patient. Differences between neoplastic (CIN) and non-ne plastic abnormal tissues (inflammation and HPV infection) yielded the largest

-3-

spectroscopic differences at an excitation wavelength of 330 nm.

5 Additionally, fluorescence spectra have been
measured *in vivo* to detect neoplastic tissues in
different organ systems. A variety of methods for making
such determinations have been proposed. For example,
ratios of autofluorescence intensity at two different
10 emission wavelengths have been used by many groups, and
scores based on multi-variate linear or non-linear
regressions and fits to extract concentrations of various
chromophores have been proposed by many others for
inclusion in decision criteria.

15 In one application, 337 nm wavelength excitation was
applied to colonic tissue. Multi-variate linear
regression analysis was used to correctly distinguish
adenomatous polyps from normal colon and hyperplastic
polyps with positive predictive value, sensitivity and
20 specificity of 86%, 86% and 80% respectively.

Tissue Classification Methods

25 Previous attempts to reliably distinguish CIN from
inflammation or HPV infection *in vivo* using colposcopy
alone have been unsuccessful. Fluorescence intensity may
be useful in this regard, but is not sufficient in itself
because analogous fluorescence intensity measurements of
the same tissue type may vary by more than a factor of
30 two from patient to patient, and by about 15% within the
same patient. Methods relating fluorescence intensities
from abnormal and normal tissues of the same patient,
however, tend to be more predictable and therefore more
diagnostically useful.

35

Thus, in general, each patient must serve as her own
control. Considering cervical tissues in a given patient

-4-

excited with 337 nm wavelength electromagnetic excitation, tissues with HPV infection are less fluorescent with than tissues with chronic inflammation, and tissues with dysplastic changes exhibit even lower fluorescence than those with HPV infection. The lowest level of fluorescence (relative to analogous fluorescence measurements on other tissue types in the same patient) is exhibited by tissues with the most abnormal form of CIN. Analogous relationships among tissue fluorescence intensity measurements in a patient may exist if excitation wavelengths other than 337 nm are used because the shape and intensity of cervical tissue spectra do not change substantially when the excitation wavelength is increased or decreased by less than 10 nm.

15

Additional information useful for tissue classification may be found in the peak emission wavelength of tissues with CIN, which is positively correlated with the peak emission wavelengths of normal tissue spectra from the same patient. This relationship, however, is not observed for tissue samples with inflammation or HPV infection.

20

Thus, a reliable method to spectroscopically classify tissue as normal or abnormal, and in the latter case to distinguish inflammation or HPV infection from CIN, is needed. Such a method could rely on one or more of the relationships described above, augmented with additional information indicative of the particular separation or classification desired.

30

SUMMARY OF THE INVENTION

The present invention includes *in vivo* spectroscopic methods and apparatus for differentiating normal tissue from abnormal tissue and for diagnosing CIN in diagnostic

35

-5-

cervical tissue samples. Diagnostic cervical tissue samples are the tissue samples to be evaluated by the non-invasive methods of the present invention. The methods include analysis of tissue fluorescence intensity spectra or portions thereof from both histologically normal tissue and histologically abnormal tissue in a patient desiring diagnosis.

Reference in this application to histologically normal cervical tissue samples in a patient subject to the diagnostic methods of the present invention refers to tissue which is presumptively histologically normal. Normal tissue samples in such subjects are selected *in vivo* and tested non-invasively as described herein to ensure a substantial likelihood that they actually represent tissue which, if histologically evaluated, would be classified normal.

In certain preferred embodiments, the spectra are represented on two-dimensional plots with fluorescence intensity being represented on the vertical axis and wavelength on the horizontal axis. For calculations involving slope measurements at predetermined wavelengths within spectra having different (unnormalized) peak values, each spectrum is normalized to its own maximum intensity value. For calculations involving the ratio of the peak intensity of a spectrum from unknown tissue (*i.e.*, from a diagnostic cervical tissue sample) to the peak intensity of a spectrum from (presumptively) normal tissue in the same patient, normalization is not performed.

Detecting Tissue Abnormality

According to the present invention, an *in vivo* method of detecting tissue abnormality in a diagnostic cervical tissue sample in a patient having known normal cervical

-6-

tissue comprises illuminating the diagnostic tissue sample and normal cervical tissue with electromagnetic radiation (preferably about 337 nm wavelength). A plurality of normal fluorescence intensity spectra are detected from the known normal cervical tissue, the spectra being obtained serially or simultaneously, preferably through fiber optics which may be placed at a fixed distance from the cervical tissue. In some embodiments, spectra may be detected through analysis of a cervical image which includes the tissue areas to be sampled.

A peak normal fluorescence intensity value is measured in each said normal fluorescence intensity spectrum, and an average peak normal fluorescence intensity calculated from said peak normal fluorescence intensity values. A fluorescence intensity spectrum is also detected from the diagnostic tissue sample, and a peak fluorescence intensity value measured from said fluorescence intensity spectrum.

A predetermined portion of the fluorescence intensity spectrum (preferably in the region corresponding to wavelengths between about 410 nm and 430 nm) from the diagnostic tissue sample furnishes slope information for calculation of a slope parameter which is indicative of tissue abnormality. The predetermined portion is empirically identified in prior clinical trials as facilitating accurate classification of tissue, and the slope parameter is preferably a function of average slope in the predetermined portion. Each spectrum is preferably normalized to its own maximum value prior to calculation of the slope parameter.

Relative peak fluorescence intensity (preferably relative to peak normal fluorescence intensity) is calculated as a function of said peak fluorescence

-7-

intensity value, and tissue abnormality is detected as a function of the calculated slope parameter and relative peak fluorescence intensity. The later function is preferably a predetermined empirical discriminant function obtained from prior clinical trials. The discriminant function may be either linear or nonlinear.

Detecting CIN

According to the present invention, an in vivo method of detecting CIN in a diagnostic cervical tissue sample in a patient having known normal cervical tissue comprises classifying the diagnostic cervical tissue sample as abnormal by a method described herein, followed by illumination of the diagnostic tissue sample and known normal cervical tissue with electromagnetic radiation, preferably of about 337 nm wavelength.

A first fluorescence intensity spectrum from the diagnostic tissue sample is detected, as is a second fluorescence intensity spectrum from the known normal cervical tissue. A first slope parameter which is indicative of CIN in the diagnostic cervical tissue sample is calculated from a predetermined portion of said first fluorescence intensity spectrum (corresponding to wavelengths between about 440 nm and 460 nm). A second slope parameter which characterizes normal cervical tissue in the patient is calculated from a predetermined portion of said second fluorescence intensity spectrum (corresponding to wavelengths between about 410 nm and about 430 nm). Both first and second slope parameters are preferably calculated after normalization of the respective fluorescence intensity spectra to peak fluorescence intensity values of 1. Additionally, both first and second slope parameters are preferably functions of average slopes in said normalized first and second fluorescence intensity spectra respectively in

-8-

regions lying substantially between wavelengths corresponding to the respective predetermined portions.

5 CIN is detected in the diagnostic cervical tissue sample as a function of said first and second slope parameters, the function preferably comprising a predetermined empirical discriminant function which, in some preferred embodiments is linear.

10

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic representation of apparatus to classify cervical tissue according to the present invention.

15

Figure 2 is a schematic representation of apparatus for multi-pixel spatial-spectral imaging of the cervix.

20 Figure 3 is a schematic representation of apparatus to acquire and process spectroscopic images of the cervix.

Figure 4 represents a population of induced fluorescence intensity spectra representing colposcopically normal and histologically abnormal tissue, with a discriminant function for detecting tissue abnormality.

25

30 Figure 5 represents a population of induced fluorescence intensity spectra representing histologically abnormal tissue (i.e., CIN, inflammation, HPV), with a discriminant function for detecting CIN.

35 Figures 6A-6F illustrate a flow chart to practice preferred embodiments of the methods of the present invention.

DETAILED DESCRIPTION

- CIN - cervical intraepithelial neoplasia
5 HPV - human papilloma virus

Normal/Abnormal Tissue Classification

- Normal/abnormal tissue classification requires
10 induced fluorescence intensity spectra from tissue areas
known to be normal with a sufficiently high probability
of accurate classification. Normal and abnormal cervical
tissues are primarily identified *in vivo* by
colposcopists. In any given patient, it is preferable to
15 collect a plurality of fluorescence intensity spectra
from tissue areas identified as normal by a colposcopist.
An expected error rate of about 10-20% has been observed,
which primarily represents samples which are
colposcopically normal but in fact comprise inflammatory
20 tissue. As explained below, provision is made for
removal of erroneously-identified normal samples, with
the result that those remaining are presumptively normal.

- As a patient is examined, peak normal fluorescence
25 intensity values are measured on each spectrum from
normal tissue. The intensity values are averaged and a
standard deviation of normal peak values calculated.
Depending on the degree of confidence required in the
screening results and the skill of the operators, a
30 portion of all spectra initially identified as
colposcopically normal are discarded (*i.e.*, the spectra
are not included in calculation of the average peak
normal fluorescence intensity, but may be assigned to the
group of spectra to be classified subsequently as normal
35 or abnormal). Criteria for discarding colposcopically
normal samples may preferably require discarding all
spectra associated with peak values which fall more than

-10-

one standard deviation below the average peak normal fluorescence intensity.

The peak fluorescence intensity of any test
5 fluorescence spectrum (associated with cervical tissue to
be evaluated for normality/abnormality) is divided by the
corresponding average normal fluorescence intensity for
that patient to yield a relative peak fluorescence
10 intensity for that spectrum. Because normal tissue tends
to have relatively high and uniform peak fluorescence
intensities in any given patient, the above division will
generally result in relative peak fluorescent intensities
clustered around a value of approximately 1 for normal
15 tissues. On the other hand, because abnormal tissue
(whether characterized as inflammation, HPV infection, or
CIN) tends to have lower-than-normal peak fluorescence
intensities, the above division will generally result in
relative peak fluorescent intensities clustered around a
value substantially less than 1 for abnormal tissues.
20 This condition furnishes a partial basis for classifying
spectra as representing either normal or abnormal tissue.

A more complete basis for identification of spectra
as representing either normal or abnormal tissue is
25 provided by examination of a slope parameter associated
with each spectrum, the parameter preferably being
derived from slopes measured in the range 400-440 nm,
preferably 410-430 nm, and in some preferred embodiments
415-425 nm, as measured on a spectrum normalized to its
30 own peak fluorescence value. The measured slope value is
largely governed by two factors, i.e., the peak emission
wavelength of fluorophores contributing to the spectrum,
and the reabsorption effect of oxy-hemoglobin with an
absorption peak at 420 nm. As more hemoglobin
35 contributes, the peak shifts to longer wavelengths and
the slope increases. Similarly, as more NADH
fluorescence contributes, the peak shifts to longer

-11-

wavelengths and the slope increases. These effects are observed in diseased tissue, and probably account in part for the capacity of methods of the present invention to differentiate types of diseased tissue on the basis of their inducted fluorescence spectra.

The parameter may be an average or tangential slope or other representative value of the range of actual slope values which will in general be found within the specified range (predetermined portion) in any normalized spectrum. Wavelengths defining the extent and location of the predetermined portion of a normalized spectrum which is indicative of tissue abnormality are determined from clinical trials involving fluorescence spectra obtained from tissue with histologically proven diagnoses. That is, the definition of the predetermined portion is empirically derived by comparing slopes over the entire wavelength range to find the portion of that range yielding the best discrimination using the methods described above.

To evaluate a diagnostic cervical tissue sample, a relative peak fluorescence intensity and a slope parameter are calculated as explained above from its induced fluorescence intensity spectrum. The calculated values may then be plotted as a point on the graph of Figure 4. The line 72 represents a predetermined empirical discriminant function which substantially separates points characterizing colposcopically normal and histologically abnormal tissue. If the point falls below line 72, the tissue sample is diagnosed as normal, whereas if the point falls above line 72, the tissue sample is diagnosed as abnormal. These decision criteria may be implemented mathematically as well as graphically by considering the equation of the line which can be derived from Figure 4. Note that the position of line 72 (slope and intercept) are subject to change with the

-12-

addition of more data points from clinical trials to those already present on Figure 4. Note also, that the position of line 72 may also be expected to change when populations having a substantially different incidence of abnormal cervical tissue from that illustrated in Figure 4 are considered.

Differentiating CIN From Other Abnormal Tissues

Although normal/abnormal tissue classification on the basis of induced fluorescence spectra is useful for preliminary screening, patients identified as having abnormal cervical tissue must be further evaluated. In particular, CIN should be differentiated from inflammation or HPV infection because of the potential for CIN to progress to invasive cancer.

As an aid to classification, a correlation has been observed between the wavelengths associated with peak intensity in corresponding fluorescence intensity spectra obtained from normal and neoplastic tissue in the same patient. Whereas three sample peak intensity wavelengths of normal spectra in a single patient were observed to be 398, 426 or 442 nm, the corresponding peak intensity wavelengths from CIN spectra in the same patient were observed to be 442, 450 or 460, respectively. Thus the peak intensity of a fluorescence intensity spectrum tends to occur at longer wavelengths in fluorescence intensity spectra from tissue with CIN, compared to corresponding spectra from normal tissue in the same patient. This wavelength shift is relatively uncommon in abnormal tissues representing HPV infection or inflammation.

A two-dimensional scatter plot was developed to map out the relationship in a population of patients between the peak emission wavelength of the abnormal spectrum and average normal spectra from the same patient. This is

-13-

shown in Figure 5, where the abscissa corresponds to the slope of the abnormal spectrum over the wavelength range 440 nm to 460 nm, and the ordinate represents the average slope of the normal spectra from the same patient over the wavelength range 410-430 nm. All spectra were normalized to a peak intensity of 1 prior to slope calculation. Note that the slope of the spectra from samples with HPV infection or inflammation does not appear to correlate to the average slope of the corresponding normal spectra (linear correlation coefficient = 0.072). However, the slope of the spectra from samples with CIN displays a positive correlation (linear correlation coefficient = 0.442) to the average slope of the corresponding normal spectra. This enables differentiation of abnormal samples with CIN from those with HPV infection or inflammation. A predetermined empirical discriminant function which allows one to carry out the differentiation for each new patient is represented by the line 82 in Figure 5, which minimizes the number of misclassified samples.

Thus, CIN tissue spectra are distinguishable from HPV or inflammation tissue spectra on a two-dimensional plot. The horizontal axis of the plot represents the value of a slope parameter obtained from an abnormal spectrum in the wavelength range of about 440 to 460 nm, while the vertical axis represents the value of a slope parameter obtained from a normal spectrum in the same patient in the wavelength range of about 410 to 430 nm.

30

A predetermined empirical function in two-dimensional space substantially separates points corresponding to CIN tissue fluorescence spectra from points corresponding to HPV or inflammation tissue spectra. In certain preferred embodiments, this function may be linear and acceptably minimize the number of misclassified points. In other preferred embodiments,

35

-14-

the function may describe a nonlinear decision surface. Determination of the preferred decision surface for any population depends on the degree to which the population is characterized by clinical data used to estimate the
5 decision surface.

Apparatus for tissue classification

Figure 1 is a schematic representation of apparatus
10 to classify cervical tissue according to the present invention. To obtain tissue fluorescence spectra, electromagnetic radiation (e.g., light, in certain embodiments) in the form of laser light from nitrogen laser 36 is applied through coupling lens 34 and single
15 fiber optic excitation fiber 32 to probe 38. Also within probe 38 are collection fiber optic fibers 30 and quartz shield 40, the shield 40 acting to keep fibers 30 and 32 properly spaced from any surface to which probe 40 is applied, application to a cervix preferably being under
20 colposcopic observation. Resulting tissue fluorescence is transmitted by fibers 30 through coupling lenses 28 to polychromator 27, and thence to intensified diode array 26. Array 26, controlled by controller 22 through gate pulser 24, detects fluorescence intensity spectra which
25 are relayed through controller 22 to computer 20. Computer 20 is programmed to classify tissue in accordance with methods described herein.

Note that laser light is not necessary for practice
30 of the present invention. Laser 36 may be replaced in some embodiments by an incandescent or other type lamp with an associated filter to produce quasi-monochromatic light. Additionally, fibers 32 and 30 may be replaced in some embodiments with fibers serving both the function of
35 illumination (excitation) and transmission of tissue fluorescence. Intensified diode array 26 and polychromator 27 may be replaced by a subassembly

-15-

comprising radiation filters and photomultiplier tubes to reduce costs in certain embodiments.

Figure 2 schematically illustrates apparatus used in certain embodiments of the present invention to simultaneously collect fluorescence spectra from multiple areas of the cervix. A source 50 of electromagnetic radiation (delivered through fiber or non-fiber optics) is used to illuminate the desired areas of the cervix (sample 51), including both some normal and some abnormal areas. A geometric array 53 of fibers 52 collects tissue fluorescence originating from known normal and unknown regions of the cervix, the latter to be diagnosed. The ends of fibers 52 proximate to imaging polychromator 54 are arranged in a linear array 55 at the entrance slit to polychromator 54. Polychromator 54 is coupled to a charge coupled device camera 56. Polychromator 54 disperses wavelength across one axis of the array, and position on the cervix varies across the other dimension. Thus this system provides a spatial-spectral image on computer-display 58 of fluorescence spectroscopic information in the cervix.

The operator identifies one or more fibers which view normal cervix. The fluorescence intensity spectrum from each fiber viewing an unknown area of the cervix is then processed by methods described herein to determine whether the tissue is histologically abnormal and whether CIN is present. This information can be presented as a spatial image of tissue histologic condition on computer-display 58.

Figure 3 is a schematic illustration of apparatus for certain embodiments of the present invention. As in Figure 2, illumination of sample 51 with electromagnetic radiation from source 50 results in fluorescence intensity spectra which are used by charge coupled

-16-

device 56 after passing through variable band pass filter 62 and colposcop imaging optics 60. Computer/display unit 68 accepts spectra from charge coupled device 56 for processing and display.

5

This system provides a two-dimensional image of variation in fluorescence intensity as a function of position on the cervix at specific wavelength band governed by the transmission characteristics (optical properties) of imaging optics 60 and filter 62, which can be rapidly changed. Images are acquired at bands centered near 398, 410, 426, 442, 450 and 460 nm sequentially. The maximum intensity I_{MAX} is identified for each pixel. A composite image indicating the peak intensity as a function of position is then formed from these images. Images indicating the slopes of the fluorescence spectra from the tissue in each pixel over the ranges 410-430 nm and 440-460 nm are calculated according to $I(426) - I(410)/[(426-410)I_{MAX}]$ and $I(460) - I(442)/[(460-442)I_{MAX}]$. The operator identifies one or more pixels corresponding to normal regions of the cervix. A relative intensity image is constructed by dividing the peak intensity image by the average normal intensity. Thus, for each pixel the relative intensity and slopes at 410-430 nm and 440-460 nm are available. These data are used to classify the state of the tissue in each pixel according to the methods presented herein. This information can be presented on computer-display unit 68 as a spatial image of tissue histologic condition.

30

Obtaining Decision Surfaces

Data points in Figure 4 represent induced fluorescence intensity spectra obtained from cervical tissue in a population of patients, each patient having both colposcopically normal tissue and histologically

35

-17-

abnormal tissue. The latter tissue includes CIN, inflammatory tissue, and tissue having HPV infection. Note that fluorescence intensities plotted along the abscissa of Figure 4 are relative to (divided by) average peak normal fluorescence intensity obtained from the population of spectra considered. Spectra from the two tissue groups are processed in accordance with methods described herein to classify the respective tissues as normal or abnormal. Decision surface 72 (a line in 2-space) is empirically established to minimize overlap of substantially normal 76 and substantially abnormal 74 groups. The equation of surface 72 as determined from Figure 4 constitutes a predetermined discriminant function useful in detecting tissue abnormality in any diagnostic cervical tissue sample when fluorescence intensity spectra are induced in the tissue sample and processed according to methods described herein.

Data points in Figure 5 represent induced fluorescence intensity spectra obtained from cervical tissue in a population containing histologically abnormal tissue, the latter tissue including CIN, inflammatory tissue, and tissue having HPV infection. Spectra from the three tissue groups are processed in accordance with methods described herein to classify the respective tissues as characteristic of CIN or not characteristic of CIN. Decision surface 82 (a line in 2-space) is empirically established to minimize overlap of substantially CIN 86 and substantially not-CIN 84 groups. The equation of surface 82 as determined from Figure 5 constitutes a predetermined discriminant function useful in detecting CIN in any histologically abnormal diagnostic cervical tissue sample when fluorescence intensity spectra are induced in the tissue sample and processed according to the methods described herein.

-18-

Figures 6A-6F illustrate a flow chart to practice preferred embodiments of the methods of the present invention. Note that steps in the flow chart continue from Figure 6A to Figure 6B, from Figure 6B to Figure 6C, and from Figure 6C to Figure 6D. Figures 6E and 6F represent subroutines to apply the particular decision rules applicable to either separation of tissue into normal and abnormal classifications (Figure 6E), or identification of CIN in samples of abnormal tissue (which may include CIN, inflammation or HPV infection) (Figure 6F). The subroutines (subcharts) illustrated in Figures 6E and 6F are called for within the steps illustrated in Figure 6D. It is assumed in applying the steps called for in Figures 6A-6F that sufficient spectra are made available to ensure that normal cervical tissue in the patient is identified and characterized by fluorescence spectra with a sufficiently high likelihood of accurate classification, as indicated in the methods described herein.

Referring to Figs. 6A-6F, the process steps executed in the diagnostic method of the present invention are shown. After the method is started, the following parameters are initialized in step 101:

counters i , k , ℓ are initialized to 1;
 N_0 - the number of normal spectra to acquire;
 N_u - the number of unknown spectra to acquire;
 M_1 - the slope of the normal/abnormal decision surface = 0.0088;
 B_1 - the intercept of the normal abnormal decision surface = -0.0005;
 M_2 - the slope of the CIN/not CIN decision surface = 4.76;
 B_2 - the intercept of the CIN/not CIN decision surface = 0.0045.

In step 102, the operator identifies the i th normal site on the cervix. The i th normal spectrum is acquired and stored in memory as $N_i(\lambda_j)$ in step 103. In step 104,

-19-

the largest (peak) intensity value is extracted from $N_i(\lambda_j)$; this value is stored in memory as P_i . In step 105, the normalized normal spectrum from site i ($NN_i(\lambda_j)$) is calculated as $NN_i(\lambda_j) = N_i(\lambda_j) / P_i$ and stored in memory. In step 106, the slope of the spectrum from 410-430 nm, S_i , is calculated from $NN_i(\lambda_j)$ as $S_i = [NN_i(430) - NN_i(410)] / (430 \text{ nm} - 410 \text{ nm})$. This value is stored in memory in step 106.

In step 107 the value of i is compared to N_0 . If $i \neq N_0$, then i is reset to $i+1$ in step 108 and the method returns to step 102. Steps 102 through 107 are repeated until counter i is equal to N_0 . At this time, step 109 is executed, wherein the average peak intensity of normal

spectra, \bar{P} , is calculated as $\bar{P} = \sum_{i=1}^{N_0} P_i / N_0$ and stored in

memory. Step 110 is then executed in which the standard deviation of the peak intensity, σ , is calculated as

$$\sigma = \sqrt{\sum_{i=1}^{N_0} (P_i - \bar{P})^2 / (N_0 - 1)} . \quad \text{This value is stored in memory}$$

and then block 111 is executed wherein counters i , ℓ and k are reset to 1.

-20-

Blocks 112 through 122 determine which of the spectra collected from areas identified as normal will be considered normal within the method and which will later be reclassified as normal or abnormal in later steps of the method. In block 112, the values of P_i and \bar{P} are compared. If $P_i - \bar{P}$ is greater than σ the spectrum from the i th sample ($N_i(\lambda_j)$) is renamed and stored in memory as $U_k(\lambda_j)$ in block 113. The type of this sample is classified later within the method. Following this, blocks 114 and 115 are executed where the counters k and i are incremented by one respectively. Control is then returned to block 112 of the method. If $P_i - \bar{P}$ is not greater than σ , the peak intensity of the corresponding spectrum (P_i) is renamed and stored as P_l in block 116. In block 117, executed next, the slope of the spectrum from 410-430 nm (S_i) is renamed and stored as S_l . The type of this sample is considered normal within the method. In block 118 the method tests to see whether $i = N_0$. If not, in block 119, the counter l is incremented by one and in block 115 the counter i is incremented by one. Control is returned to block 112 and the sequence from 112 to 118 is repeated until all acquired spectra have been tested and i is equal to N_0 . At this time, control is shifted to block 120 and N_0 is reset to l and stored in memory.

-21-

In block 121, the average peak intensity of those samples considered normal is recalculated (\bar{P}) and stored

according to $\bar{P} = \sum_{\ell=1}^{N_0} P_{\ell} / N_0$. In block 122 the average slope

of those samples considered normal (S) is calculated and

5 stored in memory according to $\bar{S} = \sum_{\ell=1}^{N_0} S_{\ell} / N_0$.

In block 123, the operator is directed to acquire the k th unknown spectrum, $U_k(\lambda_j)$; this is stored in memory.

In block 124 it is determined whether the desired number
10 of unknown spectra, N_u , have been collected by testing whether $k = N_u$. If not, in block 125 k is incremented by one and control is returned to block 123. The steps in blocks 123 to 124 are repeated until $k = N_u$, at which time, control is shifted to block 126 and k is
15 reinitialized to 1.

Control is then passed to block 127, where the peak intensity is extracted from the k th unknown spectrum, $U_k(\lambda_j)$, and stored as UP_k . The relative peak intensity of
20 the k th unknown spectrum, UR_k , is then calculated as $UR_k = UP_k / \bar{P}$ in block 128 and stored. The normalized unknown spectrum, $NU_k(\lambda_j)$ is then calculated as $NU_k(\lambda_j) = U_k(\lambda_j) / UP_k$ and stored in block 129. In block 130, the slope of the k th normalized unknown spectrum from 410-430 nm (US_{1k}) is

-22-

calculated as $US_{1k} = (NU_k(430nm) - NU_k(410 nm)) / (430 nm - 410 nm)$ and stored.

In block 132 the type of the kth unknown sample is
5 determined as normal or abnormal by following the steps
in Figure 6E. In block 132a, the parameter Y_{k1} is
calculated for the kth unknown spectrum as $Y_{k1} = M_1UR_k + B_1$; this value is stored in memory. In block 132b, US_{1k}
is compared to Y_{k1} . If US_{1k} is less than Y_{k1} , the sample
10 is classified as normal; this information is stored in
memory in block 133 and control is transferred to block
137. If US_{1k} is not less than Y_{k1} , the sample is
classified as abnormal and control is passed to block
134. In block 134, the steps of Figure 6F are used to
15 diagnose whether or not the abnormal sample contains CIN.
In block 134a, the parameter Y_{k2} is calculated for the kth
unknown spectrum as $Y_{k2} = M_2US_{2k} + B_2$. This value is stored
in memory. In block 134b, the values of S and Y_{k2} are
compared. If S is less than Y_{k2} then the sample is
20 classified as CIN and this information is stored in
memory in block 135. If S is not less than Y_{k2} then the
sample is classified as abnormal, but not containing CIN,
and this information is stored in memory in block 136.
When the sample type of the kth unknown sample has been
25 classified, in blocks 133, 135 or 136, control is passed
to block 137, where the values f k and N_u are compared.
If k is not equal to N_u , the counter k is incremented by

-23-

one in block 138 and control returns to block 127. The steps in blocks 127 through 137 are repeated until k is equal to N_u , indicating that all unknown samples have been classified and the method is stopped in block 139.

-24-

CLAIMS

1. An *in vivo* method of detecting tissue abnormality in a diagnostic cervical tissue sample, comprising:

5

illuminating the diagnostic tissue sample with
electromagnetic radiation;

10

detecting a fluorescence intensity spectrum from the
diagnostic tissue sample;

15

measuring a peak diagnostic tissue fluorescence
intensity value from said fluorescence
intensity spectrum;

20

calculating from a predetermined portion of said
fluorescence intensity spectrum a diagnostic
tissue slope parameter which is indicative of
tissue abnormality;

25

calculating relative peak diagnostic tissue
fluorescence intensity as a function of said
peak fluorescence intensity value; and
detecting tissue abnormality as a function of said
diagnostic tissue slope parameter and said
relative peak diagnostic tissue fluorescence
intensity.

-25-

2. The method of claim 1, said illuminating step comprising, illuminating said diagnostic tissue sample with electromagnetic radiation having a wavelength of
5 about 337 nm.

3. The method of claim 1, said step of calculating said diagnostic tissue slope parameter comprising, calculating
10 said diagnostic tissue slope parameter from a portion of said fluorescence intensity spectrum corresponding to wavelengths between about 410 nm and about 430 nm.

15 4. The method of claim 1, wherein said slope parameter is calculated after normalization of said fluorescence intensity spectrum with said peak fluorescence intensity value.

20

5. The method of claim 4, said step of calculating said diagnostic tissue slope parameter comprising, calculating said diagnostic tissue slope parameter as a function of an average slope in said normalized fluorescence
25 intensity spectrum in said predetermined portion.

6. The method of claim 1, further comprising

-26-

illuminating a known normal cervical tissue with
said electromagnetic radiation;

detecting a plurality of normal fluorescence
5 intensity spectra from the known normal
cervical tissue;

measuring a peak normal tissue fluorescence
intensity value in each said normal
10 fluorescence intensity spectrum; and

calculating an average peak normal tissue
fluorescence intensity from said peak normal
tissue fluorescence intensity values;

15 said step of calculating relative peak fluorescence
diagnostic tissue fluorescence intensity
comprising, calculating relative peak
diagnostic tissue fluorescence intensity as a
20 function of both said peak fluorescence
intensity value and said average peak normal
tissue fluorescence intensity.

25 7. The method of claim 6, wherein said calculating
relative peak fluorescence intensity step comprises
calculating relative peak fluorescence intensity as a

-27-

function of both said peak fluorescence intensity value and said average peak normal fluorescence intensity.

- 5 8. The method of claim 1, said step of detecting tissue abnormality comprising, detecting tissue abnormality as a predetermined empirical discriminant function of said abnormal tissue slope parameter and said relative peak abnormal tissue fluorescence intensity.

10

9. The method of claim 8, said step of detecting tissue abnormality comprising, detecting tissue abnormality as a predetermined linear empirical discriminant function of
15 said abnormal tissue slope parameter and said relative peak abnormal tissue fluorescence intensity.

10. An *in vivo* method of detecting tissue abnormality in
20 a diagnostic cervical tissue sample in a patient,
 comprising:

 identifying a presumptively histologically normal
 cervical tissue sample from the patient;

25

 illuminating the diagnostic tissue sample and said
 presumptively histologically normal tissue
 sample with electromagnetic radiation;

-28-

detecting a first fluorescence intensity spectrum
from the diagnostic tissue sample;

5 detecting a second fluorescence intensity spectrum
from said presumptively histologically normal
tissue sample;

calculating a slope parameter indicative of tissue
abnormality from said first fluorescence
10 intensity spectrum;

calculating an intensity parameter characteristic of
normal tissue from said second fluorescence
intensity spectrum;

15 calculating a discriminant parameter as a function
of said slope and intensity parameters;

detecting tissue abnormality in the diagnostic
20 cervical tissue sample by substituting said
discriminant parameter in a predetermined
discriminant function.

25 11. An *in vivo* method of detecting CIN in a diagnostic
cervical tissue sample in a patient having presumptively
known normal cervical tissue, comprising:

-29-

illuminating the diagnostic tissue sample and
presumptively known normal cervical tissue with
electromagnetic radiation;

5 detecting a first fluorescence intensity spectrum
from the diagnostic tissue sample;

detecting a second fluorescence intensity spectrum
from the presumptively known normal cervical
10 tissue;

calculating from a predetermined portion of said
first fluorescence intensity spectrum a first
slope parameter which is indicative of CIN in
15 the diagnostic cervical tissue sample;

calculating from a predetermined portion of said
second fluorescence intensity spectrum a second
slope parameter which characterizes
20 presumptively normal cervical tissue in the
patient; and

detecting CIN in the diagnostic cervical tissue
sample as a function of said first and second
25 slope parameters.

-30-

12. The method of claim 11, said illuminating step comprising, illuminating said diagnostic tissue sample with electromagnetic radiation having a wavelength of about 337 nm.

5

13. The method of claim 11, said step of calculating said first slope parameter comprising, calculating said first slope parameter from a portion of said first
10 fluorescence intensity spectrum corresponding to wavelengths between about 440 nm and about 460 nm.

14. The method of claim 11, said step of calculating
15 said second slope parameter comprising, calculating said second slope parameter from a portion of said second fluorescence intensity spectrum corresponding to wavelengths between about 410 nm and about 430 nm.

20

15. The method of claim 11, wherein said first and second slope parameters are calculated after normalization of said first and second fluorescence intensity spectra to peak fluorescence intensity values
25 of 1.

-31-

16. The method of claim 15, wherein said first and second slope parameters are functions of average slopes in said normalized first and second fluorescence intensity spectra respectively, said slopes being
5 measured in predetermined regions of said normalized first and second fluorescence intensity spectra respectively, said regions lying substantially between wavelengths corresponding to said predetermined portions of said first and second fluorescence intensity spectra
10 respectively.

17. The method of claim 11, said step of detecting CIN comprising, detecting CIN as a predetermined empirical
15 discriminant function of said first and second slope parameters.

18. The method of claim 17, said step of detecting CIN
20 comprising, detecting CIN as a predetermined linear empirical discriminant function of said first and second slope parameters.

25 19. An apparatus for *in vivo* detection of tissue abnormality in a diagnostic cervical tissue sample in a patient having presumptively known normal cervical tissue, comprising:

-32-

a source of electromagnetic radiation to be applied to the diagnostic cervical tissue sample and the presumptively known normal cervical tissue;

5 at least one radiation detector adapted to detect a fluorescence intensity spectrum induced in the diagnostic cervical tissue sample and a plurality of normal fluorescence intensity spectra induced in the presumptively known
10 cervical tissue by said radiation source;

a computer, connected to said source of electromagnetic radiation and said radiation detector, programmed to measure a peak normal
15 fluorescence intensity value in each said normal fluorescence intensity spectrum, to calculate an average peak normal fluorescence intensity from said peak normal fluorescence intensity values, to measure a peak
20 fluorescence intensity value from said fluorescence intensity spectrum induced in the diagnostic cervical tissue sample, to calculate from a predetermined portion of said fluorescence intensity spectrum a slope
25 parameter which is indicative of tissue abnormality, to calculate relative peak fluorescence intensity as a function of said peak fluorescence intensity value and said

-33-

average peak normal fluorescence intensity, and to detect tissue abnormality as a function of said slope parameter and said relative peak fluorescence intensity.

1/11

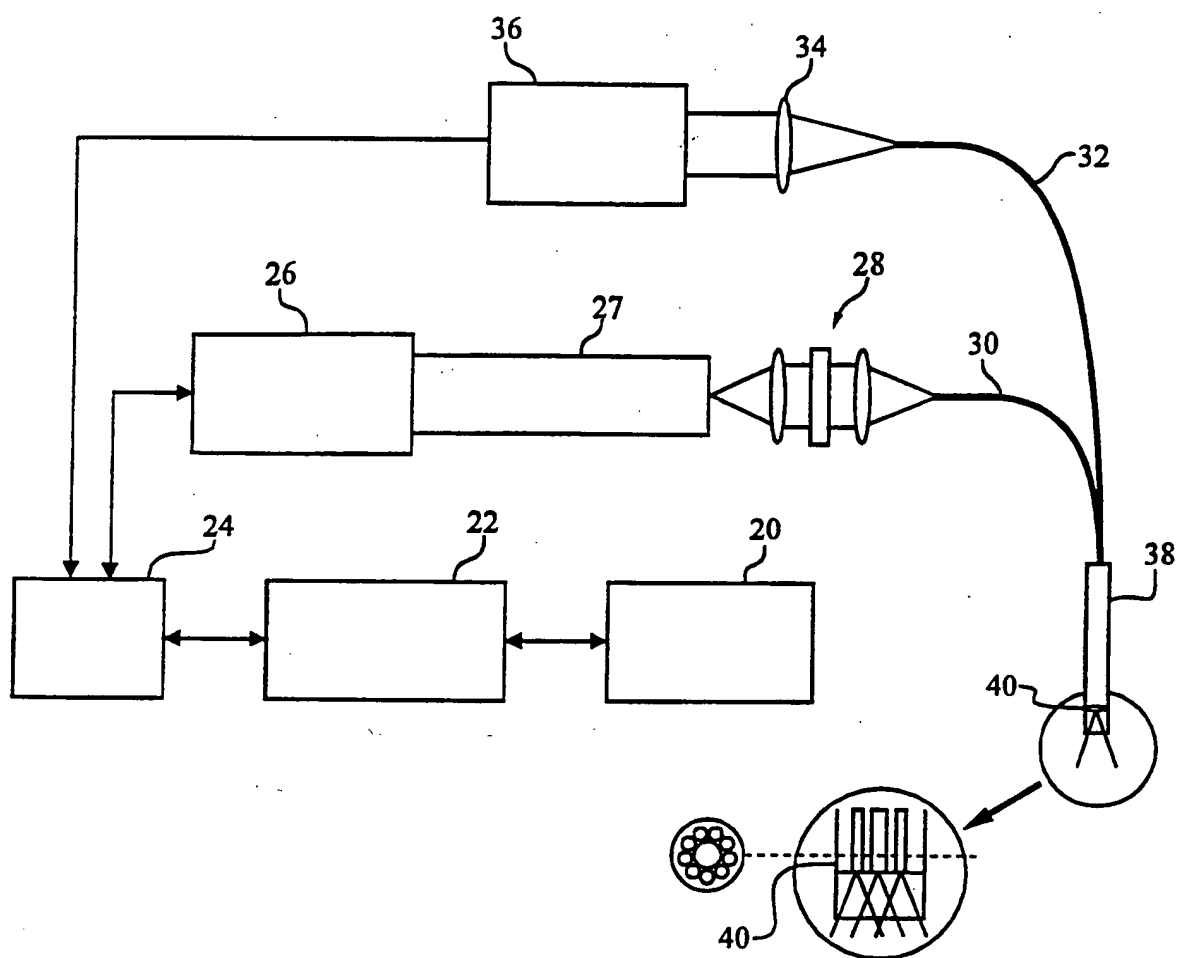


FIGURE 1

2/11

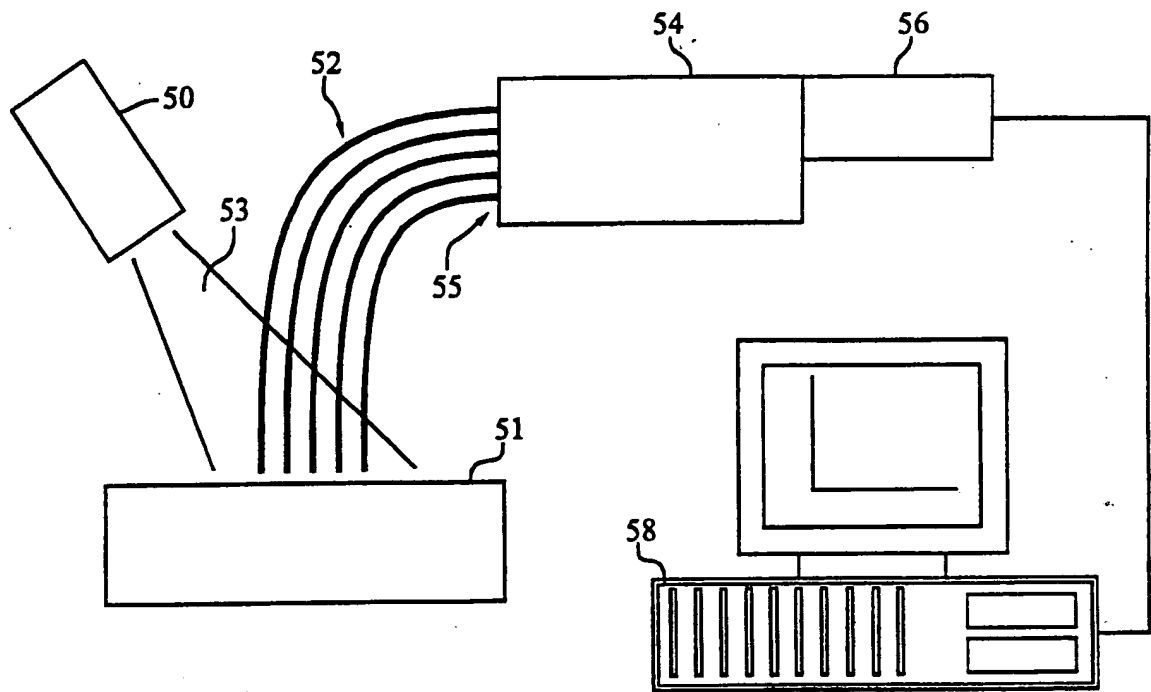


FIGURE 2

3/11

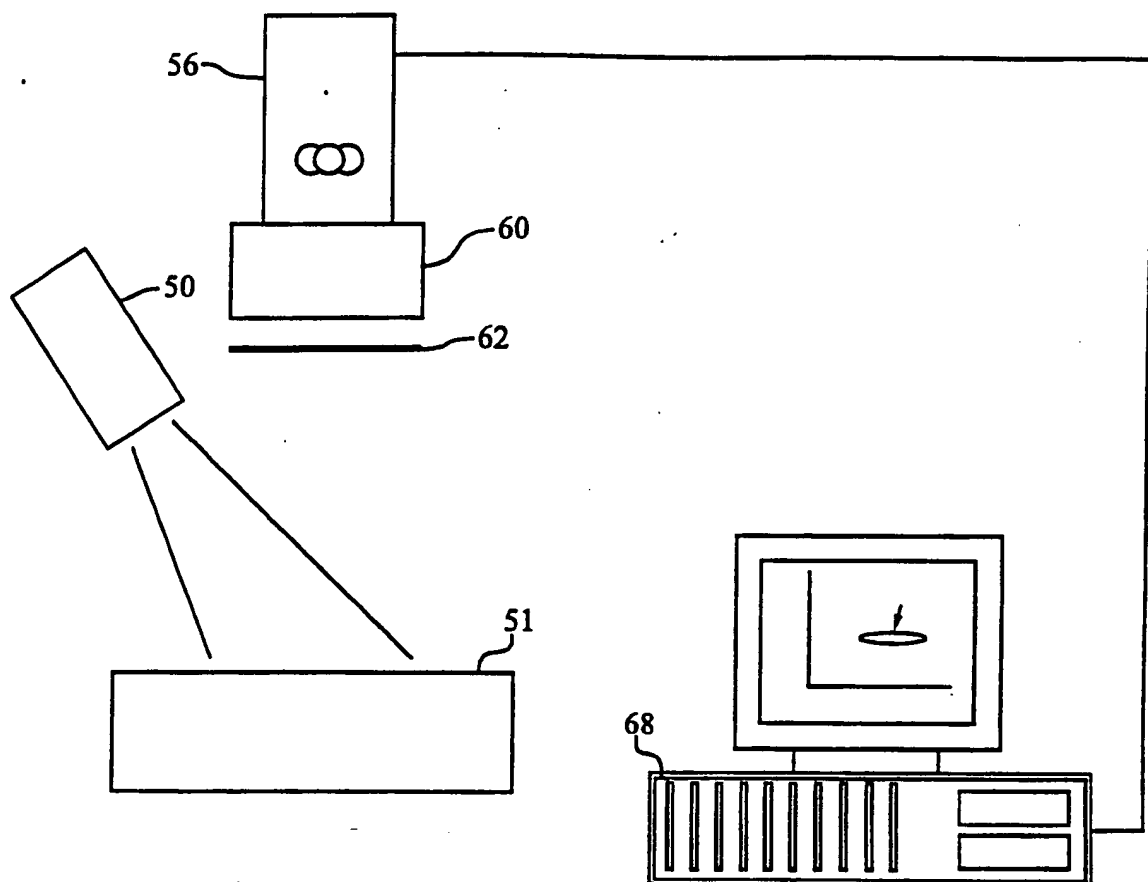


FIGURE 3

4/11

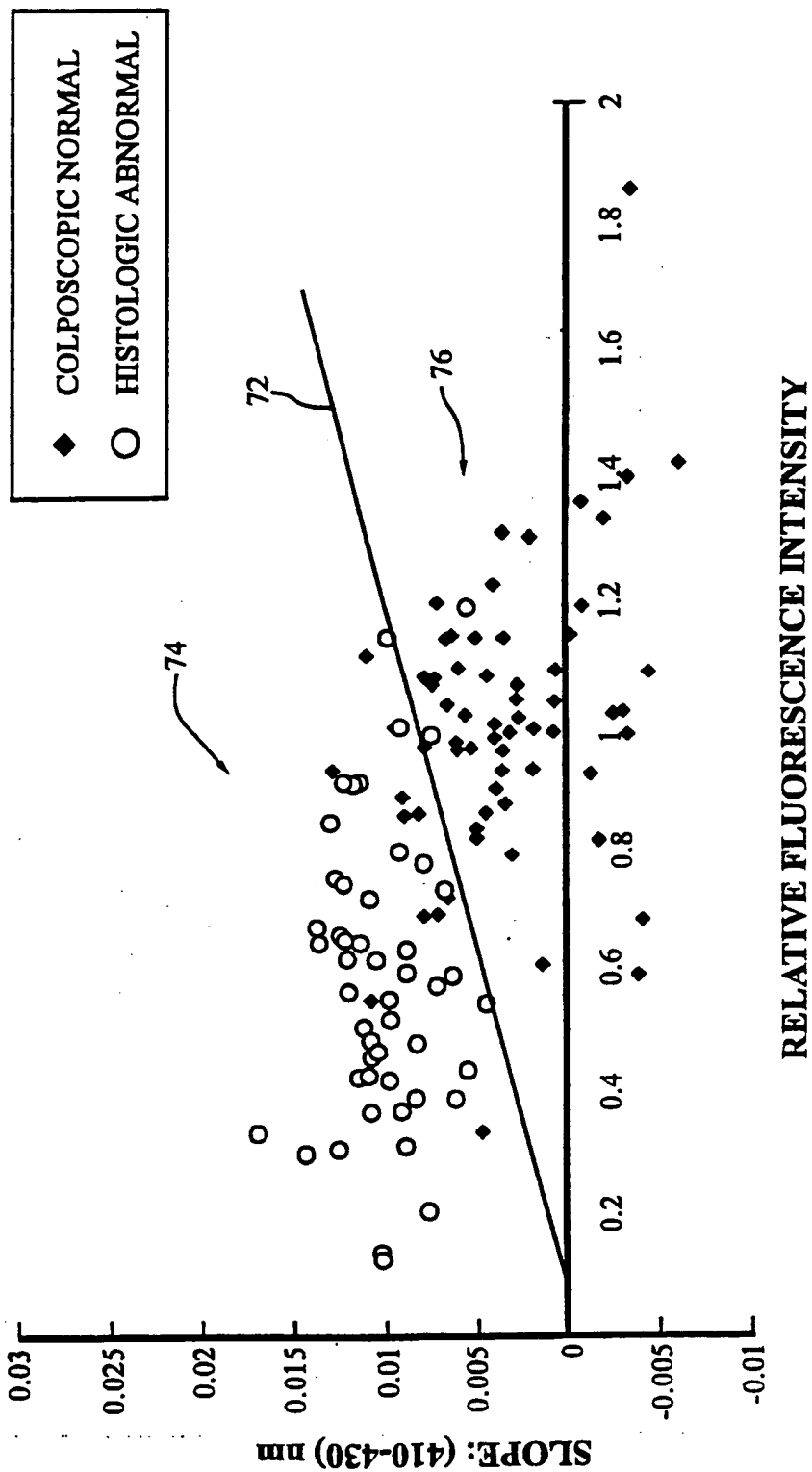


FIGURE 4

5/11

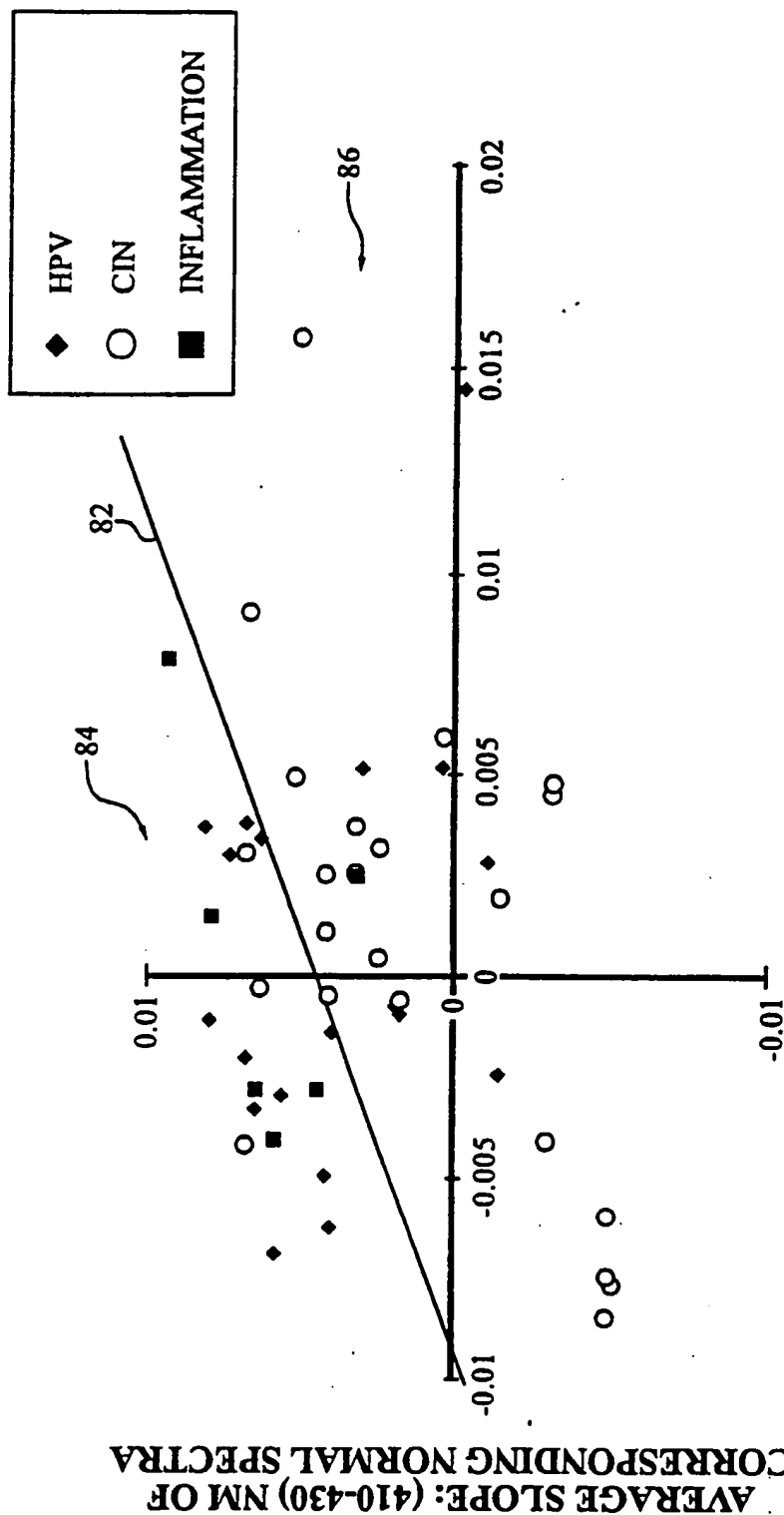


FIGURE 5

6/11

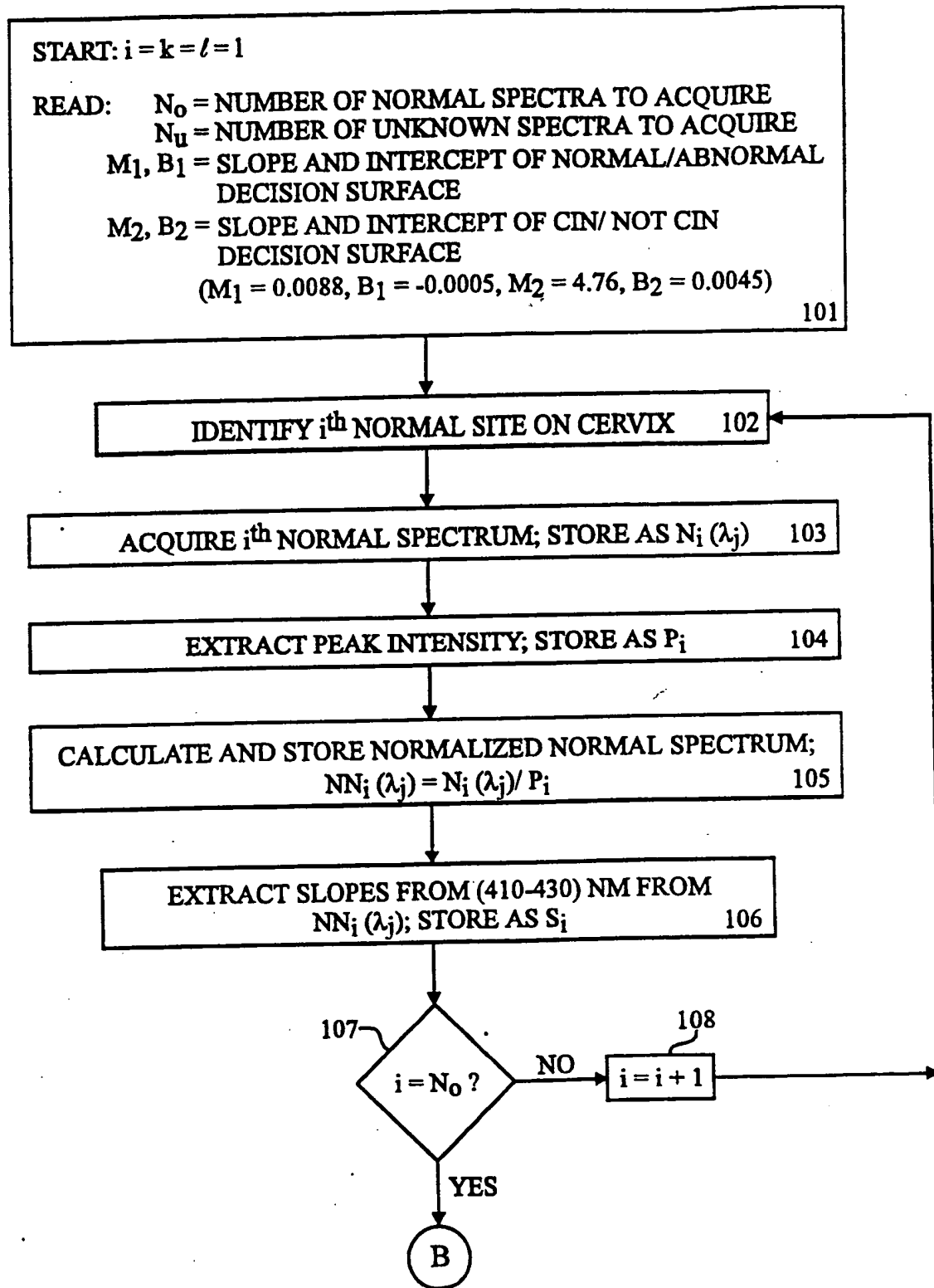


FIGURE 6A

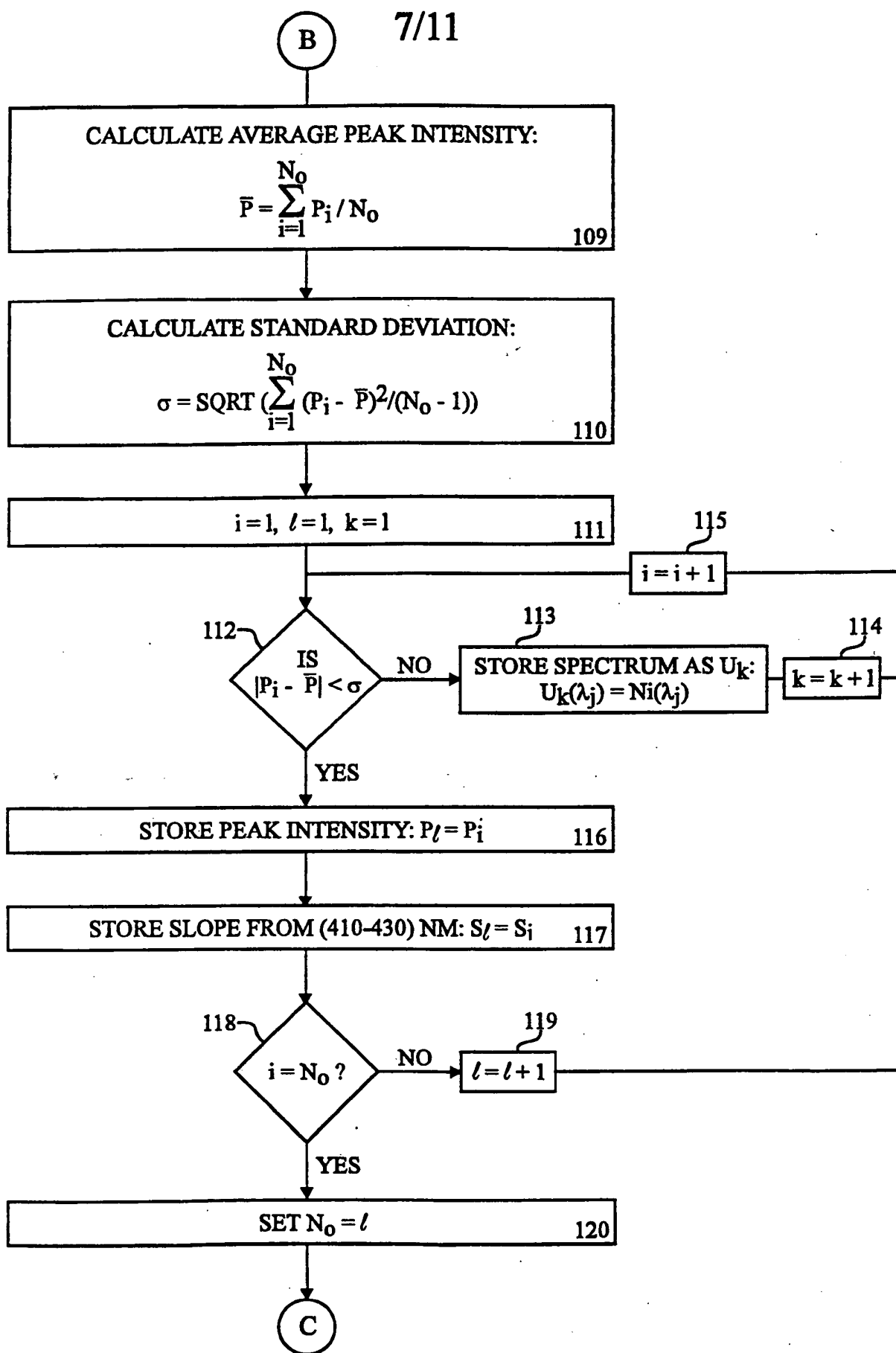


FIGURE 6B

8/11

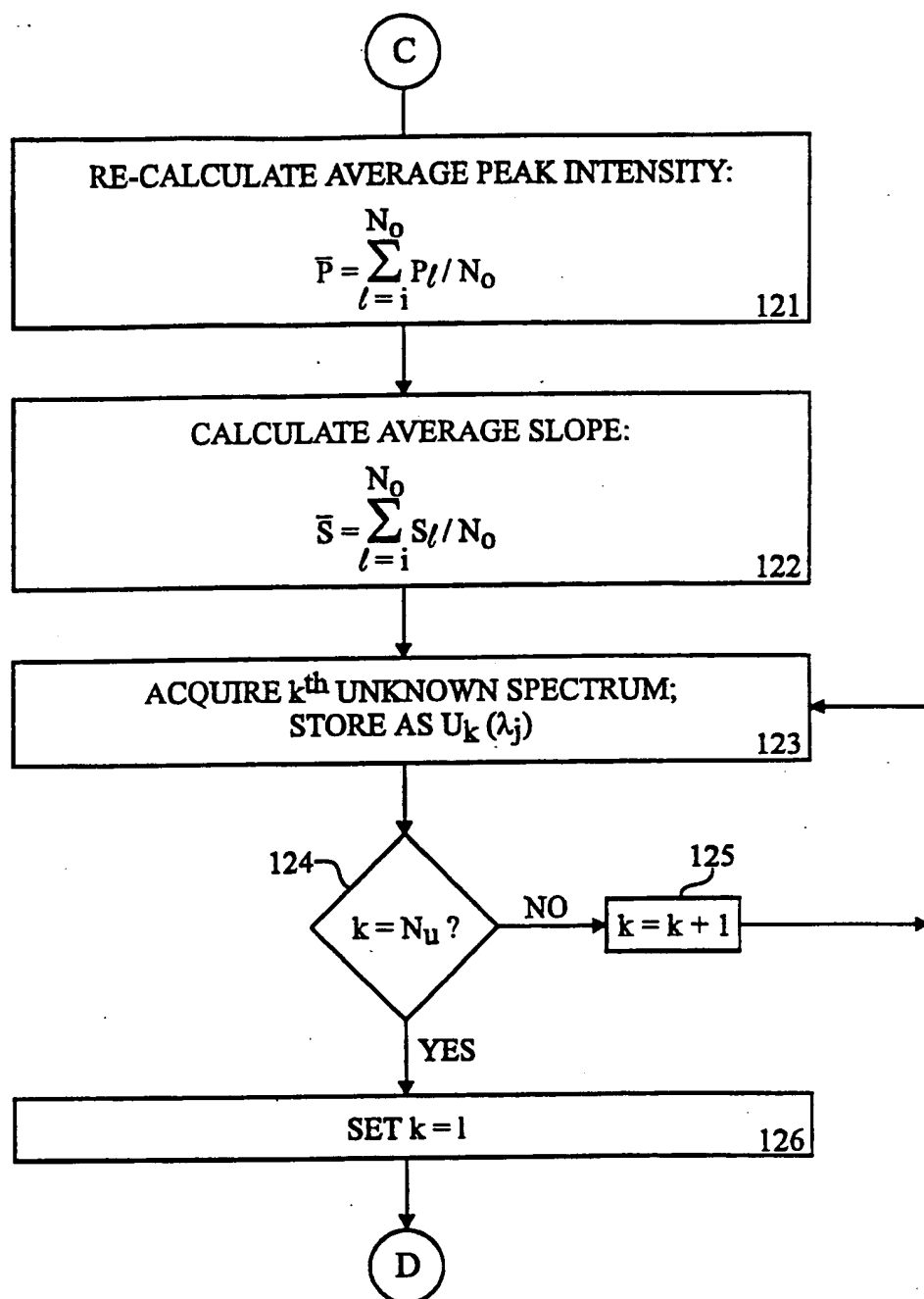
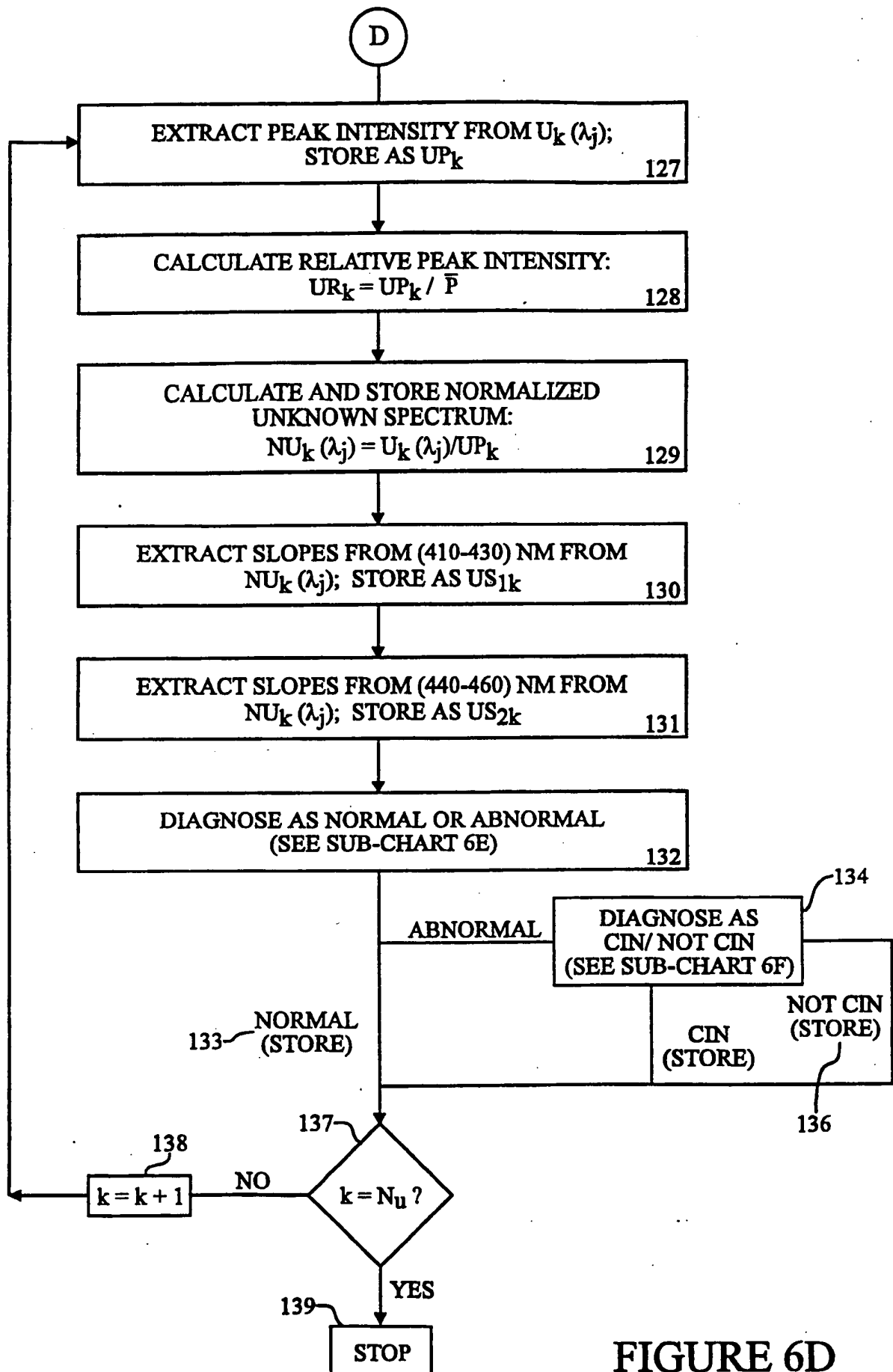


FIGURE 6C

9/11



10/11

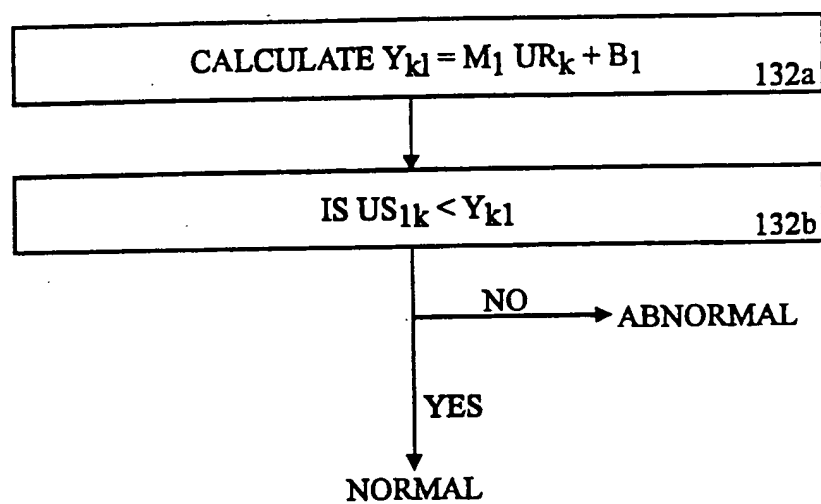


FIGURE 6E

11/11

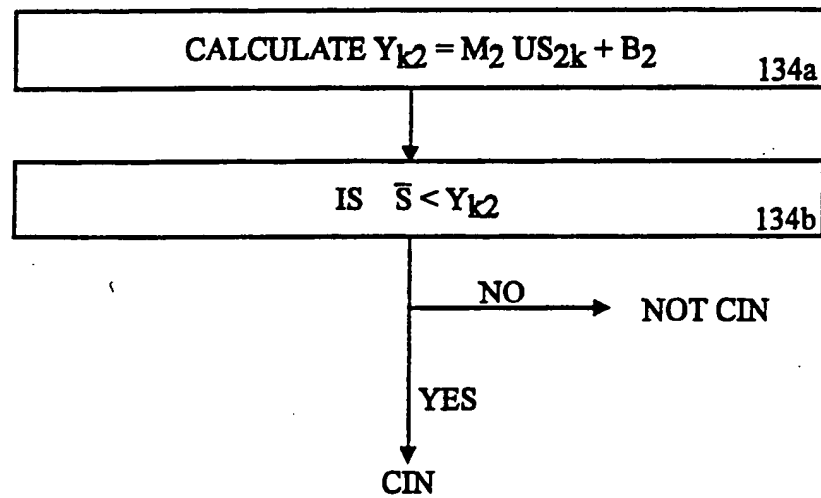


FIGURE 6F

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US94/05230

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :A61B 6/00

US CL :128/665

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 128/664, 665; 606/3, 14-16; 607/88-93

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

NONE

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

NONE

C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category* | Citation of document, with indication, where appropriate, of the relevant passages | Relevant to claim No. |
|-----------|--|-----------------------|
| X | US, A, 5,125,404, (KITRELL ET AL.), 30 June 1992. See entire document. | 19 |
| A | US, A, 5,131,398, (ALFANO ET AL.), 21 July 1992. See Abstract. | 1, 10, 11, 19 |

☐

Further documents are listed in the continuation of Box C.

☐

See patent family annex.

| | |
|---|--|
| * Special categories of cited documents: | * T later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention |
| * A document defining the general state of the art which is not considered to be part of particular relevance | * X document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone |
| * E earlier document published on or after the international filing date | * Y document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art |
| * L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified) | * G document member of the same patent family |
| * O document referring to an oral disclosure, use, exhibition or other means | |
| * P document published prior to the international filing date but later than the priority date claimed | |

Date of the actual completion of the international search

20 JULY 1994

Date of mailing of the international search report

30 SEP 1994

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer

RUTH S. SMITH

Telephone No. (703) 308-3063

THIS PAGE BLANK (USPTO)

THIS PAGE BLANK (USPTO)